Available online at www.sciencedirect.com
SCIENCE DIRECT
Renewable and Sustainable Energy Reviews
9 (2005) 624–637
RENEWABLE & SUSTAINABLE ENERGY REVIEWS
www.elsevier.com/locate/rser

# An application of a combined wind and solar energy system in Izmir

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Received 31 March 2004; accepted 29 June 2004

**Abstract**

In this work, a combined system which is produced electrical energy from both solar radiation via solar cells and wind energy by using wind turbine was studied. For wind energy, measurements of wind velocities at 12 m height were taken. Then, these values were calculated for 42 m by using Hellmann equation. After that, wind energy converted to the electrical energy. However, value of solar radiation from solar cells was taken at the optimum slope angle of collector which provided higher energy production for each 1 h during this application. Thus, obtained data from each system were used together for finding total energy. For this study, measurements, which would be used in calculation of wind energy and solar energy were taken for four years between 1995 and 1998 in Izmir. As a result, energy of the combined system could support each other when one of them produces energy insufficiently.


*Keywords:* Combined system; Energy; Renewable energy; Solar energy; Wind energy

**Contents**



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1364-0321/$ - see front matter 
doi:10.1016/j.rser.2004.06.002

## 1. Introduction

Environmental friendly renewable energies are divided into six main categories according to their source: geothermal energy, hydraulic energy, wind energy, wave energy, biomass solar energy and can be converted to the electrical energy. Therefore, electrical energy can be obtained from these renewable energies by using different application. However, to produce electrical energy from wind energy using wind turbine and from solar radiation via solar cells are more popular applications than others.

Electrical energy, which is separately produced from wind and the solar energies and given directly into the national grid, can solve this problem to a certain extent. Because solar energy system, itself, cannot provide a continuous source of energy due to the low availability during the no-sun period and during the winter [1]. Also, wind system, itself, cannot satisfy constant load demands due to different magnitude of wind speed from one hour to another [2]. Therefore, the biggest problem in separately use of wind energy and solar energy is their discontinuity. For this reason, we can offer several suggestion for solution of this problem. One of the solutions for discontinuity of wind, is to be install a lot of wind turbines in different place which have different energy potential and which feed the same national grid to obtain constant power of electrical energy. Another solution is to prevent discontinuity between solar and wind energy which is fed the same interconnected system with balancing each other for different time. So electrical energy obtained from the solar radiation supports the combined system when the energy obtained from wind turbine is insufficient for national grid. In this work, we will study last one.

## 2. Experimental work

### 2.1. Wind energy

At Institute of Solar Energy in University of Ege, average wind velocities at 12 m height were measured [3]. Demirer Company installed the first wind farm. In that farm, a turbine rotor hub is at 42 m height in Germiyan village in Cesme, Izmir, Turkey. When the values of the wind turbine at 42 m height examine, it was seen that, good results could be obtained. We also know that, using Hellmann Coefficient $\mu$, wind velocity at the given

## Nomenclature

| | |
|---|---|
| $A_{sol.}$ | area of tilted surface for solar cells ($m^2$) |
| $A_{wind}$ | area of vertical surface for wind propeller ($m^2$) |
| $\bar{E}_{sun}$ | solar radiation energy on the unit area (W h) |
| $E_T$ | annual energy needs (W h) |
| $\bar{E}_{wind}$ | wind energy per unit cross-sectional area of propeller (W h/$m^2$) |
| $h$ | height above sea level (m) |
| $H$ | height for calculated wind velocity (m) |
| $H_{ref.}$ | reference height (m) |
| $\bar{I}_b$ | direct solar radiation on the unit area of the horizontal surface (W/$m^2$) |
| $\bar{I}_{bT}$ | direct solar radiation on the unit area of the tilted surface for optimum slope (W/$m^2$) |
| $\bar{I}_c$ | total solar radiation on the unit area of the horizontal plane in a clear sky day (W/$m^2$) |
| $\bar{I}_{cb}$ | direct solar radiation on the unit area of the horizontal surface in the cloudless day (W/$m^2$) |
| $\bar{I}_{cd}$ | diffuse solar radiation on the unit area of the horizontal surface in the cloudless day (W/$m^2$) |
| $\bar{I}_d$ | diffuse solar radiation on the unit area of the horizontal surface (W/$m^2$) |
| $\bar{I}_{dT}$ | diffuse solar radiation on the unit area of the tilted surface for optimum slope (W/$m^2$) |
| $\bar{I}_T$ | power of total solar radiation on the unit area of the tilted surface for optimum slope (W/$m^2$) |
| $\bar{I}_{Tmean}$ | average of total power of solar radiation on the unit area |
| $\bar{I}_{Ty}$ | total solar radiation power on the horizontal surface (W/$m^2$) |
| $\bar{P}_{mean}$ | average wind power per unit cross-sectional area of propeller (W/$m^2$) |
| $\bar{P}_{wind}$ | wind power per unit cross-sectional area of propeller (W/$m^2$) |
| $V_w$ | calculated wind velocity (m $s^{-1}$) |
| $V_{wref.}$ | reference wind velocity at the reference height (m $s^{-1}$) |
| *Greek letters* | |
| $\beta_{Opt.}$ | optimum slope of the surface (deg.) |
| $\delta$ | declination angle (deg.) |
| $\Delta t$ | time interval (s) |
| $\phi$ | latitude angle (deg.) |
| $\eta_{sol.}$ | general efficiencies of the proportion of solar energy on the area of the tilted surface to the end usage of energy |
| $\eta_{wind}$ | general efficiencies of the proportion of wind energy on the area of vertical surface to the end usage of energy |
| $\mu$ | Hellmann coefficient (–) |
| $\Theta_z$ | zenith angle (deg.) |
| $\rho$ | reflectance ratio of the surface (–) |
| $\rho_a$ | air density (kg/$m^3$) |

| | |
|---|---|
| $\sigma_{sc}$ | solar constant (W/m$^2$) |
| $\tau$ | transmittance coefficient (–) |
| $\tau_b$ | transmittance coefficient for direct solar radiation (–) |
| $\tau_d$ | transmittance coefficient for diffuse solar radiation (–) |
| $\omega$ | hour angle (deg.) |

height can be transferred to the different height. For this reason, wind velocities at 12 m height are necessary to transfer to height of 42 m by the following equation [4]

$$V_w = V_{wref.}\left(\frac{H}{H_{ref.}}\right)^{\mu}, \tag{1}$$

where $V_w$ is the wind velocity. Values of Hellmann coefficient, which primarily depends on wind direction, which varies according to the state of barriers (e.g. high buildings, high mountain), were taken into account as an average value. Therefore, Hellmann coefficient depends on the place where wind velocities are measured [5] and are given in Table 1. In this work, Hellmann coefficient was taken as 0.3 [5], because Izmir where the measurements were taken is a city with high buildings.

At the wind velocity, $V_w$, wind power per unit of cross-sectional area is given by the following equation:

$$\bar{P}_{wind} = \tfrac{1}{2}\rho_a V_w^3 \quad (\mathrm{W/m^2}). \tag{2}$$

Wind power per unit of cross-sectional area varies with time, $\Delta t$. Therefore, wind energy is obtained by the following equation

$$\bar{E}_{wind} = \tfrac{1}{2}\rho_a V_w^3\, \Delta t \quad (\mathrm{W\,h/m^2}), \tag{3}$$

where air density is accepted $\rho_a = 1.23$ kg/m$^3$ [2]. If $\bar{P}_{wind,i}$ is known, average wind power $\bar{P}_{mean}$ in this time period can be calculated by the following equation:

$$\bar{P}_{mean} = \frac{\sum_{i=1}^{n} \bar{P}_{wind,i}\Delta t_i}{\sum_{i=1}^{n} \Delta t_i}. \tag{4}$$

### 2.2. Solar energy

Total solar radiation power $\bar{I}_{Ty}$ (W/m$^2$), which have influence on unit area of a horizontal plane, was calculated [6]. The highest solar radiation was occurred if

Table 1
Variance of Hellmann coefficient dependent on the place [5]

| Definition of the place | $\mu$ (Hellmann coefficient) |
|---|---|
| Open sea, coast | 0.14 |
| Open land, fields | 0.18 |
| Woodland, and city | 0.28 |
| City with high buildings | 0.4 |

the incoming solar radiation is perpendicular to the surface. Therefore, at first, optimum slope angle of tilted surface that depended on a latitude and declination angle was calculated. After that, to find out total solar radiation on the unit area of tilted surface for optimum slope, direct and diffuse radiation on the tilted surface for optimum slope were calculated for an hour period and summed. Calculation of the solar radiation on the unit area of tilted surface for optimum slope can be explained as follows [7].

When solar radiation is perpendicular to the surface, optimum slope of the surface can be calculated by the following equation

$$\beta_{\text{Opt.}} = \phi - 1.5\delta - \frac{|\delta|\phi}{180} \quad \text{(degree)}, \tag{5}$$

where $\phi$ is latitude angle and declination angle $\delta$ can be calculated by the following equation

$$\delta = 23.45 \sin\left[360\frac{(284+n)}{365}\right] \quad \text{(degree)}, \tag{6}$$

where the day of year $n$ can be accepted first of January as a beginning day [8].

In this work, hourly optimum slope angles of the tilted surface which belonged to Izmir were determined and the average values of each year have been found 41.45° for 1995, 1997 and 1998; and 41.43° for 1996.

Power of total solar radiation on the unit area of the tilted surface for optimum slope can be estimated by the following equation

$$\bar{I}_{\text{T}} = \bar{I}_{\text{bT}} + \bar{I}_{\text{dT}} \quad (\text{W/m}^2), \tag{7}$$

where $\bar{I}_{\text{bT}}$, $\bar{I}_{\text{dT}}$ represent direct solar radiation and diffuse solar radiation on the unit area of the tilted surface for optimum slope, respectively. Direct solar radiation on the unit area of the tilted surface for optimum slope can be calculated by the following equation

$$\bar{I}_{\text{bT}} = \bar{I}_{\text{b}}\left[\frac{\cos(\phi-\beta)\cos\delta\cos\omega + \sin(\phi-\beta)\sin\delta}{\cos\phi\cos\delta\cos\omega + \sin\phi\sin\delta}\right] \quad (\text{W/m}^2), \tag{8}$$

where $t$ is the time between 1 and 24 h and $\omega$ is hour angle. The hour angle can be calculated by the following equation

$$\omega = 15^\circ(t-12) \quad \text{(degree)}. \tag{9}$$

$\bar{I}_{\text{b}}$ represents direct solar radiation the unit area of the horizontal surface. It can be calculated by the following equation

$$\bar{I}_{\text{b}} = \bar{I}_{\text{Ty}} - \bar{I}_{\text{d}} \quad (\text{W/m}^2). \tag{10}$$

$\bar{I}_{\text{d}}$ represents diffuse solar radiation on the unit area of the horizontal surface. It can be obtained from the following equation

$$\frac{\bar{I}_d}{\bar{I}_{Ty}} = \begin{cases} 1.00 - 0.1\left(\frac{\bar{I}_{Ty}}{\bar{I}_c}\right) \Leftarrow 0 \le \frac{\bar{I}_{Ty}}{\bar{I}_c} < 0.48 \\ 1.11 + 0.0396\left(\frac{\bar{I}_{Ty}}{\bar{I}_c}\right) - 0.789\left(\frac{\bar{I}_{Ty}}{\bar{I}_c}\right)^2 \Leftarrow 0.48 \le \frac{\bar{I}_{Ty}}{\bar{I}_c} \le 1.11 \\ 0.2 \Leftarrow \frac{\bar{I}_{Ty}}{\bar{I}_c} \ge 1.11 \end{cases} \tag{11}$$

where $\bar{I}_c$ is the total solar radiation on the unit area of the horizontal plane in a clear sky day can be calculated by the following equation

$$\bar{I}_c = \bar{I}_{cd} + \bar{I}_{cb} \quad (\mathrm{W/m^2}), \tag{12}$$

where $\bar{I}_{cd}$ and $\bar{I}_{cb}$ represent diffuse solar radiation and direct solar radiation on the unit area of the horizontal surface in the cloudless day, respectively.

Power of the total extraterrestrial radiation on the unit area of the horizontal surface (W/m$^2$) is given below

$$\bar{I}_0 = \frac{12}{\pi}\sigma_{sc}\left[1 + 0.033\cos\left(\frac{360n}{365}\right)\right]\left[\cos\phi\cos\delta(\sin\omega_2 - \sin\omega_1) + \frac{2\pi(\omega_2-\omega_1)}{360}\sin\phi\sin\delta\right], \tag{13}$$

where value of solar constant $\sigma_{sc}$ is approximately accepted 1353 W/m$^2$ [7]. For calculation of $\bar{I}_c$ in Eq. (12), $\bar{I}_{cb}$, which represents direct solar radiation on the unit area of the horizontal plane in the clear sky day and $\bar{I}_{cd}$, which represents diffuse solar radiation on the unit area of the horizontal plane in the cloudless day must be calculated. They are given by the following equations

$$\bar{I}_{cb} = \tau_b \bar{I}_0 \quad (\mathrm{W/m^2}), \tag{14}$$

$$\bar{I}_{cd} = \tau_d \bar{I}_0 \quad (\mathrm{W/m^2}), \tag{15}$$

where $\tau$ is a transmittance coefficient and $\tau_d$ is transmittance coefficient for diffuse solar radiation

$$\tau_d = 0.271 - 0.2939\tau_b, \tag{16}$$

where $\tau_b$ is the transmittance coefficient for direct solar radiation. It is calculated by the following equation:

$$\tau_b = a_0 + a_1\, e^{(-k/\cos\Theta_z)}. \tag{17}$$

Constants in Eq. (17) are given below

$$a_0 = r_0[0.4237 - 0.00821(6-h)^2], \tag{18}$$

$$a_1 = r_1[0.5055 + 0.00595(6.5-h)^2], \tag{19}$$

$$k = r_k[0.2711 + 0.001858(2.5-h)^2], \tag{20}$$

Table 2
Transmittance coefficient for power of direct sun radiation [7]

| Climate type | $r_0$ | $r_1$ | $r_k$ |
|---|---|---|---|
| Tropical | 0.95 | 0.98 | 1.02 |
| Middle-altitude degree, summer | 0.97 | 0.99 | 1.02 |
| Subtropical, summer | 0.99 | 0.99 | 1.01 |
| Middle-altitude degree, winter | 1.03 | 1.01 | 1.00 |

where $h$ is a height above sea level and accepted as 12 m for solar energy in Izmir. Constants in Eqs. (18)–(20) are given in Table 2. In this work, for these constants, average values of summer and winter for middle latitude degree, $r_0$, $r_1$, $r_k$ can be accepted as 1, 1, 1.01, respectively. In Eq. (17), zenith angle, $\Theta_z$, which is the angle between the vertical and the line to the sun, can be calculated as below:

$$\cos \Theta_z = \cos \delta \cos \phi \cos \omega + \sin \delta \sin \phi. \tag{21}$$

Diffuse solar radiation on the unit area of the tilted surface for optimum slope can be estimated by using Eqs. (10) and (11) as below

$$\bar{I}_{dT} = \bar{I}_d \left( \frac{1 + \cos \beta}{2} \right) + (\bar{I}_b + \bar{I}_d)\rho \left( \frac{1 - \cos \beta}{2} \right) \quad (\mathrm{W/m^2}), \tag{22}$$

where $\rho$ is a reflectance ratio of the surface. It depends on the location properties that are given in Table 3. In this work, $\rho$ is accepted as 0.2 [7].

If $n$ number of $\Delta t_i$, which represents a period of time and average of total power of solar radiation on the unit area, $\bar{I}_{Ti}$ are known, $\bar{I}_{Tmean}$ is defined by the following equation:

$$\bar{I}_{Tmean} = \frac{\sum_{i=1}^{n} \bar{I}_{Ti} \Delta t_i}{\sum_{i=1}^{n} \Delta t_i} \quad (\mathrm{W/m^2}). \tag{23}$$

If energy of solar radiation $\bar{E}_{Ti}$ which have affected on the unit area at the determined time period $\Delta t_i$ is known, solar radiation energy on the unit area during this time period can be calculated by Eq. (24):

$$\bar{E}_{sol.} = \sum_{i=1}^{n} \bar{E}_{Ti} \Delta t_i \quad (\mathrm{W\,h/m^2}). \tag{24}$$

At the Institute of Solar Energy in University of Ege, total solar radiation $\bar{I}_{Ty}$ (W/m$^2$), which have affected on the unit area of horizontal plane, was measured. Table 4 shows the energy of solar radiation coming to the unit area of horizontal surface and tilted surface of optimum slope angle and availability of energy acquisition as a percentage provided by

Table 3
Reflectance ratio dependent on location properties [7]

| Location properties | Newly-snowed | Light colored building surface | Fodder | Green plant | Water surface |
|---|---|---|---|---|---|
| $\rho$ | 0.75 | 0.60 | 0.30 | 0.20 | 0.04 |

Table 4
Availability of energy (%) for optimum slope

| | Years | | | |
|---|---|---|---|---|
| | 1995 | 1996 | 1997 | 1998 |
| Energy of sun rays coming to the horizontal surface (kW h/m$^2$) | 1711.72 | 1659.42 | 1673.25 | 1643.15 |
| Energy of sun rays coming to the tilted surface of optimum slope (kW h/m$^2$) | 2282.76 | 2230.32 | 2240.23 | 2213.45 |
| Availability of energy (%) for optimum slope | 33 | 34 | 34 | 35 |

tilted surface of optimum slope angle for four years. When Table 4 is examined, the percentage of energy of solar radiation that have affected on the unit area of tilted surface, which has optimum slope angle, is 33–35% higher than energy of solar radiation, which have affected on the unit area of horizontal surface.

Our aim is to find out whether solar energy and wind energy support each other. Therefore, monthly amounts of solar radiation on the unit area of the plane surface of optimum slope angle for each year and amount of wind energy on the unit area of

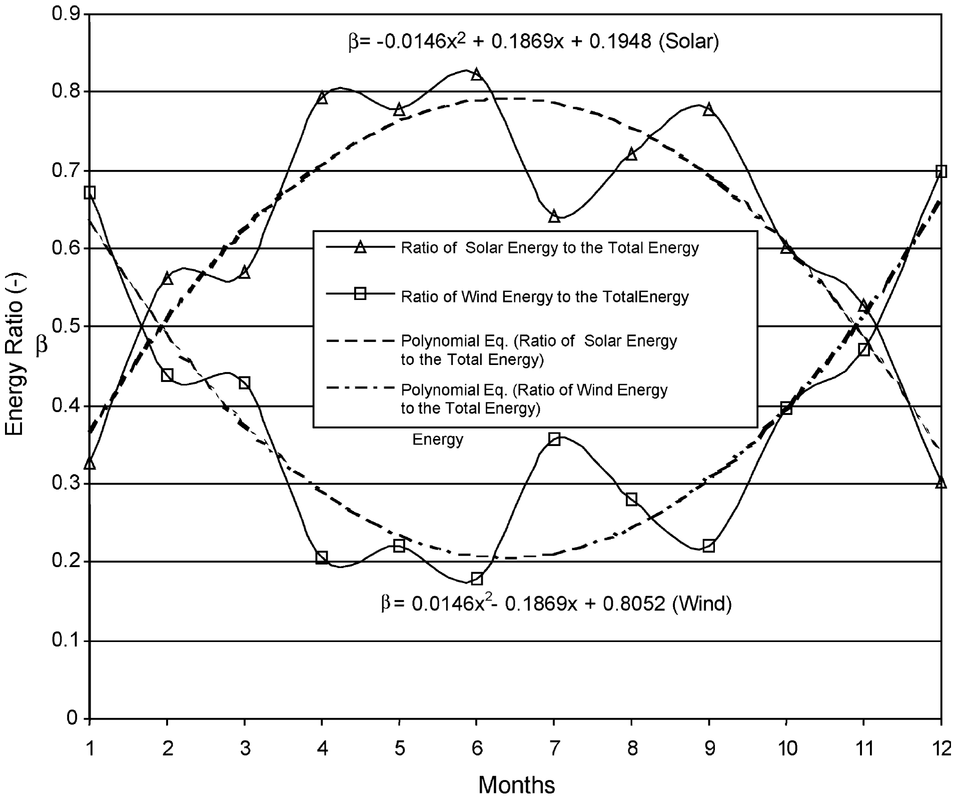



Fig. 1. Variation of energy ratio according to months for 1995.

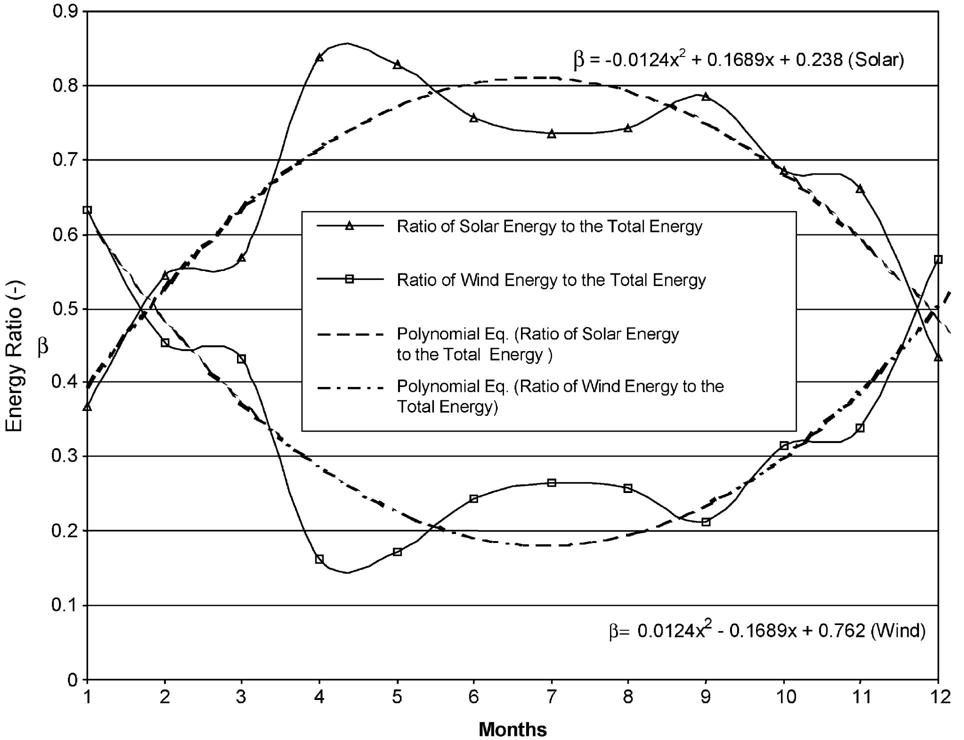



Fig. 2. Variation of energy ratio according to months for 1996.

a cross-section of the turbine propeller were divided by total energy of wind and solar on the unit area and this propotion was called 'energy proportion $\beta$'. Monthly variations of energy ratio for each of the years are given in the equation below and related Figs. 1–4

$$\beta = ax^2 + bx + c, \quad x = 1, 2, 3, \ldots, 12, \tag{25}$$

where $\beta$ is the energy ratio and $x$ is the month of year. As a result of study of these figures, a balance between wind energy and solar energy occurred at the examined years.

## 3. Analysis

If we consider that electrical energy produced by combined system is delivered to the national grid and users of the electricity want to meet their annual energy needs from the national grid, $E_T$ (W h), equation about $E_T$ is written as below

$$E_T = \eta_{wind} A_{wind} \sum_{i=1}^{n} \bar{P}_{wind i} + \eta_{sol.} A_{sol.} \sum_{i=1}^{n} \bar{I}_{Ti}, \tag{26}$$

where $\eta_{wind}$ is the general efficiency of the proportion of wind energy on the propeller area of wind turbine $A_{wind}$ placed as vertical position to the end usage of energy and $\eta_{sol.}$ is

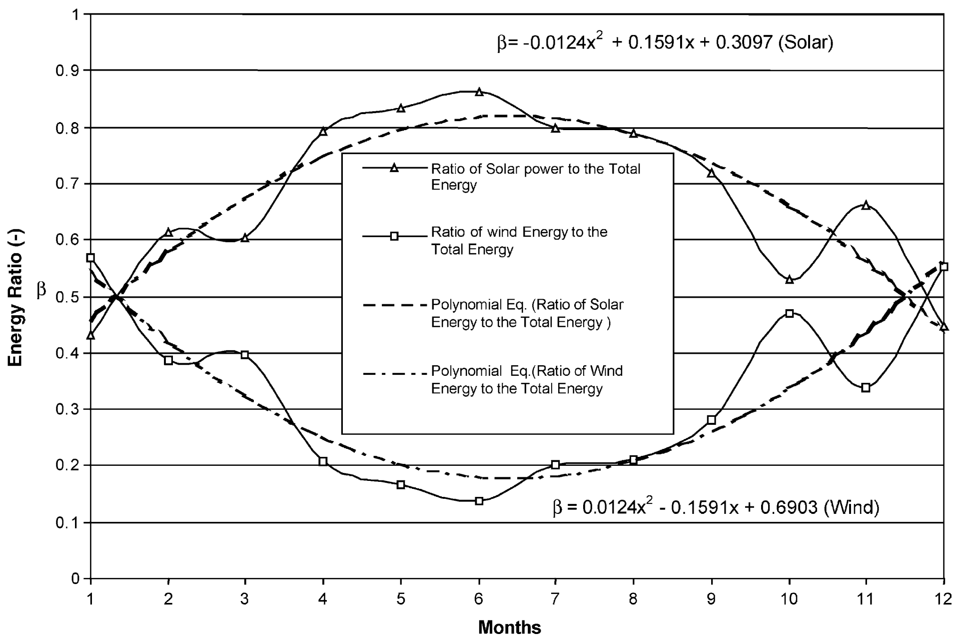



Fig. 3. Variation of energy ratio according to months for 1997.

the general efficiency of the proportion of solar energy on the area of the tilted surface $A_{sol.}$ to the end usage of energy. General efficiency is not a constant value. But in this work, we assume that $\eta_{wind}$ is equal to 0.20 [9] and $\eta_{sol.}$ is equal to 0.10 [10]. For constant $E_T$ value, Eq. (26) can be used

$$A_{wind} = \frac{E_T - A_{sol.}\eta_{sol.}\sum_{i=1}^{n}\bar{I}_{Ti}}{\eta_{wind}\sum_{i=1}^{n}\bar{P}_{windi}}, \quad (27)$$

where

$$A_{wind} = E_T/(245\,544.2) - 0.93A_{sol.} \quad \text{(for 1995)},$$

$$A_{wind} = E_T/(200\,747) - 1.11A_{sol.} \quad \text{(for 1996)},$$

$$A_{wind} = E_T/(189\,962) - 1.18A_{sol.} \quad \text{(for 1997)},$$

$$A_{wind} = E_T/(168\,719) - 1.31A_{sol.} \quad \text{(for 1998)}.$$

It is assumed that the consumption of average value of electrical energy for each person is 1450 kW h for 1995 in Turkey, electrical energy need for 1000 people by combined system are $1450\times10^6$ W h. Therefore, electrical energy of $1450\times10^6$ W h must be given to the national grid. Table 7 shows that, balance between cross-sectional area of propeller and plane area of solar cells can be given as a numerical example according to the combined system which provides amount of annually total electrical energy.

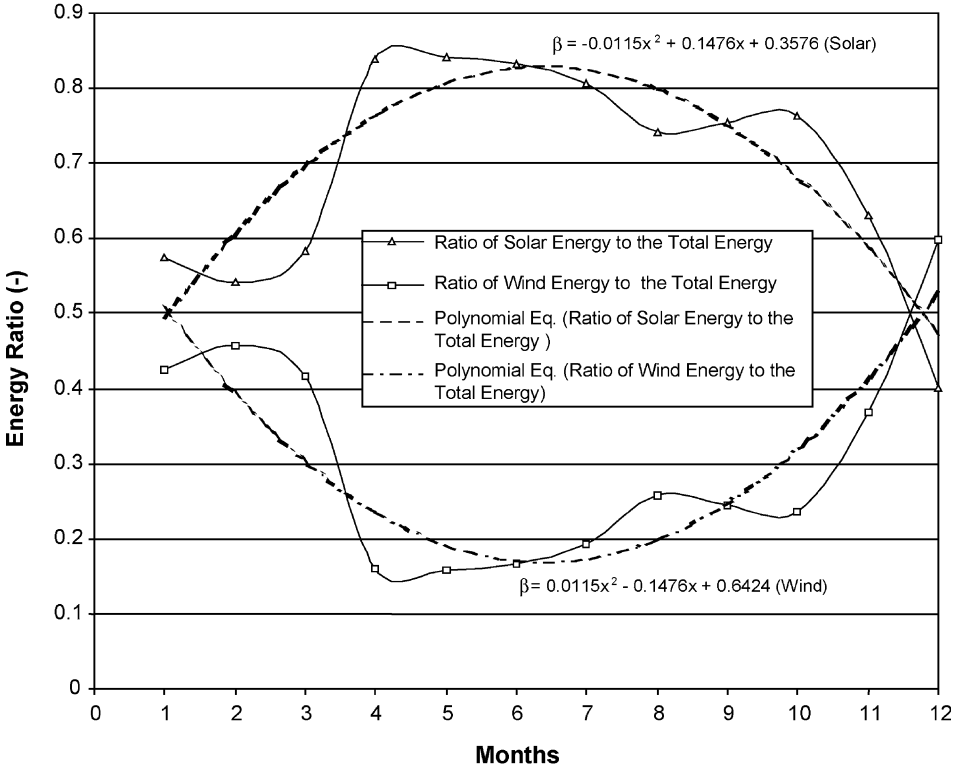



Fig. 4. Variation of energy ratio according to months for 1998.

When Table 7 is examined, it is shown that either only wind energy or only solar energy or together can provide electrical energy for a 1000 people. If this energy is only provided from wind energy, cross-sectional area of propeller of 5905.25 $m^2$ or wind turbine of 43.36 m radius is required. If this energy just provided from solar energy, cross-sectional area of photovoltaic cells must be 6349.73 $m^2$.

## 4. Result and discussion

Balance of the wind energy and solar energy have been studied with the assistance of the data from measurement of total coming solar radiation on a unit of horizontal plane and hourly wind velocity during four years between 01.01.1995 and 31.12.1998, on the wind turbine of 12 m high, at the Institute of Solar Energy in University of Ege and from their calculation from equations which are given previously. Obtained results were given in Tables 4–7. Table 4 shows solar radiation coming to the unit area of horizontal surface and tilted surface of optimum slope angle and availability of energy acquisition as a percentage used by tilted surface of optimum slope angle for four years. When Table 4 is examined,

Table 5
Monthly average wind and solar radiation values according to different years [6]

| Months | Years | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1995 | | 1996 | | 1997 | | 1998 | |
| | $\bar{I}_{Tort}$ | $\bar{P}_{mean}$ | $\bar{I}_{Tmean}$ | $\bar{P}_{mean}$ | $\bar{I}_{Tmean}$ | $\bar{P}_{mean}$ | $\bar{I}_{Tmean}$ | $\bar{P}_{mean}$ |
| January | 84.38 | 172.80 | 98.78 | 170.44 | 127.06 | 166.95 | 116.44 | 86.35 |
| February | 174.63 | 135.95 | 121.61 | 134.90 | 169.65 | 106.20 | 179.05 | 150.61 |
| March | 222.17 | 166.95 | 205.33 | 155.73 | 243.21 | 159.87 | 199.07 | 141.69 |
| April | 307.29 | 80.21 | 316.74 | 61.09 | 239.88 | 62.69 | 297.65 | 56.56 |
| May | 381.20 | 108.38 | 361.68 | 74.76 | 380.86 | 75.40 | 303.74 | 56.95 |
| June | 430.31 | 92.77 | 451.63 | 145.89 | 398.62 | 64.18 | 426.98 | 86.14 |
| July | 391.82 | 217.74 | 419.05 | 151.55 | 421.39 | 106.96 | 430.21 | 102.78 |
| August | 380.89 | 147.50 | 360.37 | 125.09 | 361.06 | 95.61 | 375.75 | 130.26 |
| September | 303.59 | 86.18 | 278.97 | 75.72 | 321.64 | 124.96 | 289.86 | 94.13 |
| October | 235.54 | 155.23 | 205.25 | 94.48 | 191.39 | 168.74 | 211.07 | 65.06 |
| November | 124.02 | 110.59 | 142.32 | 72.90 | 126.69 | 65.33 | 120.62 | 70.69 |
| December | 86.87 | 200.95 | 82.25 | 106.74 | 81.11 | 100.25 | 78.57 | 117.13 |

solar radiation that acts on the unit area of tilted surface, which has optimum slope angle, is 33–35% more than solar radiation that acts on the unit area of horizontal surface.

In Table 5, monthly average wind power and solar radiation power values for each year, in Table 6, monthly wind energy and solar radiation energy values for each year are given. Furthermore, in Table 6, wind and solar radiation energy are given annually. Because of the easiest way to make a comparison between energies for different years, energy values in 1995 was determined as a hundred units, so energy values in others were determined according to 1995. In this work, total 8760 numbers hourly data for 1995, 1997, 1998 and 8784 numbers hourly data for 1996 were obtained.

Table 6
Monthly wind and solar radiation energy values according to different years [6]

| Months | Years | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 1995 | | 1996 | | 1997 | | 1998 | |
| | $\bar{E}_{sol.}$ | $\bar{E}_{wind}$ | $\bar{E}_{sol.}$ | $\bar{E}_{wind}$ | $\bar{E}_{sol.}$ | $\bar{E}_{wind}$ | $\bar{E}_{sol.}$ | $\bar{E}_{wind}$ |
| January | 62.78 | 128.56 | 73.49 | 126.81 | 94.53 | 124.21 | 86.63 | 64.24 |
| February | 117.35 | 91.56 | 84.64 | 70.57 | 114.01 | 71.37 | 120.32 | 101.21 |
| March | 165.30 | 124.21 | 152.76 | 115.86 | 180.95 | 118.94 | 148.11 | 105.42 |
| April | 221.25 | 57.75 | 228.05 | 43.99 | 172.71 | 45.14 | 214.31 | 40.73 |
| May | 283.62 | 80.63 | 269.10 | 55.62 | 283.36 | 56.10 | 225.98 | 42.37 |
| June | 309.82 | 66.80 | 325.18 | 105.04 | 287.00 | 46.21 | 307.43 | 62.02 |
| July | 291.51 | 162.00 | 311.77 | 112.75 | 313.52 | 79.58 | 320.07 | 76.47 |
| August | 283.38 | 109.74 | 268.12 | 93.06 | 268.63 | 71.14 | 279.56 | 96.91 |
| September | 218.58 | 62.05 | 200.86 | 54.52 | 231.58 | 89.97 | 208.70 | 67.77 |
| October | 175.24 | 115.49 | 152.70 | 70.29 | 142.39 | 125.55 | 157.04 | 48.41 |
| November | 89.29 | 79.62 | 102.47 | 52.49 | 91.22 | 47.04 | 86.55 | 50.90 |
| December | 64.63 | 149.51 | 61.20 | 79.41 | 60.35 | 74.58 | 58.45 | 87.15 |
| Total | 2282.76 | 1227.72 | 2230.32 | 1003.74 | 2240.23 | 949.81 | 2213.45 | 843.59 |
| Percentage | 100 | 100 | 98 | 80 | 98 | 77 | 97 | 69 |

Table 7
Example of choosing design area of combined system for 1995

| Year | 1995 | |
|---|---|---|
| Design area | $A_{sol.}$ ($m^2$) | $A_{wind}$ ($m^2$) |
| Energy quantity, $E_T = 1450 \times 10^6$ (W h/year) | 0 | 5905.25 |
| | 100 | 5812.28 |
| | 1000 | 4975.58 |
| | 6349.73 | 0 |

When Table 6 is examined, range of solar radiation energy from low to high for concerning years is between 1995 and 1998. The ranges of wind energy from low to high for concerning years are the same as above. Another result was that annual differences of wind energy between 1995 and 1998 (100−69) were more evident than annual differences of solar radiation energy between 1995 and 1998 (100−97), which can be obtained from Table 6.

From Figs. 1–4, wind and solar energies that act on the unit area balance each other between February–March and October–November. Figs. 1–4 show a balance between wind energy and solar energy. Generally, during the winter season, the potential of wind energy is high, the potential of solar energy is low and vice versa during the summer season. For this reason, electrical energy produced from wind turbine and solar cells can feed the same national grid system because they balance each other. Therefore, discontinuity problem can be solved by energy plant in the combination of wind and solar energy.

To choose design area of combined system, infinite solutions are possible for a linear equation as it is understood from Table 7 and Eq. (27). The equation, which will be used in application, depends on some criteria as economics and place.

As a result of examination of all tables and figures, it can be seen that wind and solar energy support each other. Also seen that either just solar energy system or just wind energy system cannot satisfy constant load demands for national grid. Therefore, wind and solar energy systems can be used as a combined system to meet continuous energy demand.

## Acknowledgements

We want to thank Professor Dr M. Colak, Project Director of ‘Investigation of Relationship between Solar Energy Systems and Wind and another Climatic Condition’, Ege University Research Fund, Turkey, Report No. 1993/GEE/007 (in Turkish) and Professor Dr N. Özbalta, Project Director of ‘Analysis of Solar Radiation Data in Bornova Izmir Turkey’, Ege University Research Fund, Turkey, Report No. 1993/GEE/004 (in Turkish) for providing valuable data from their projects.

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